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COMPUTATION OF THE LAMINAR COMPRESSIBLE BOUNDARY LAYER

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The problem of the flow of a two-dimensional compressible viscous fluid over a body can be treated in such a way that after the introduction of the boundary layer theory, the whole flow field is divided into two regions: namely; the exterior or inviscid flow region and the boundary or viscous layer along the body. The equations describing the flow in the boundary layer are first-order approximations to the Navier-Stokes equations. When the viscous flow and exterior inviscid flow are matched to first-order, the flows in the two regions can be computed independently. At hypersonic speeds the presence of the boundary layer can not be neglected in solving the inviscid flow field about slender bodies. There is an interaction between the boundary-layer equations and the external flow problem. Therefore, the inviscid flow equations and the boundary; layer equations must be solved simultaneously. It is not a simple task, however, to obtain analytic solutions to these equations. Many attempts have been made at getting approximate solutions. One method which used finite difference techniques shows considerable promise. It is also quite general since it is applicable to arbitrary body shape, variable fluid properties and any specified surface temperature. In an AFOSR sponsored program of research in the computation of the laminar compressible boundary layer this method has been investigated by Professor I. Flugge-Lotz of Stanford University.

Excellent results have been obtained so far. The most recent results will appear in an article in the Journal of Aerospace Sciences in the near future. This article entitled, "The Finite-Difference Solution of the Boundary Layer with Displacement Thickness Interaction" by F. G. Blottner and I. Flugge-Lotz presents a method for solving the laminar compressible boundary layer equations with and without displacement thickness interaction. An implicit finite-difference scheme of high accuracy with satisfactory convergence and reasonable computation time is used. The scheme appears to be stable without any restrictions on grid size

since the results obtained corroborate this conclusion. Also, the numerical results with interaction are in agreement with the weak and strong interaction theory and available experimental results.

The importance of this to the design of high speed vehicles in the earth's atmosphere is evident when one notes that laminar boundary layer flow prevails in a large region of high speed surfaces because of the lower Reynolds number characteristic of high altitude flight.

THE BOUNDARY LAYER "CUSHION" AROUND A FLUTTERING CYLINDRICAL SHELL

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Most missiles and aircraft use thin structural coverings which are susceptible to flutter when the vehicle reaches supersonic speeds. As a result, a concerted effort by academicians, engineers, and designers has been under way in this country for the past ten years to better understand the flutter properties of thin elastic plates and shells. The general problem has been given the name "panel flutter."

Panel flutter is of interest to the aircraft and missile designer because he must make all surfaces exposed to supersonic flow rigid enough to prevent flutter. This phenomenon has occurred in the X-15 and may occur on the newer aerospace vehicles because of the increased demand for lightness, and hence for less rigid coverings. Physically, this type of flutter is a rippling wave which moves across the skin, causing fatigue at rivets or other fasteners. It is generally a relatively mild type of flutter.

Academic circles have been interested in the field for some time because of the delicate nature of the problem. Mathematically, panel flutter is a non-self-adjoint problem and has pointed out some weaknesses in approximate mathematical methods used for solution. Also, it has shown that existing unsteady aerodynamic theories are not accurate enough in the transonic range and for cylinders at higher Mach numbers.

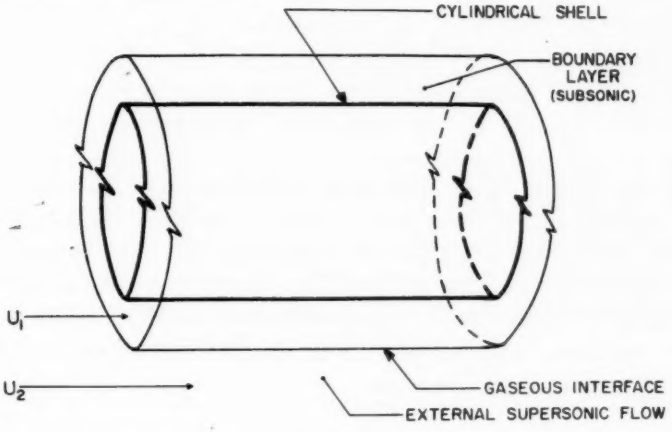
The Office of Aerospace Research has supported work in this area at Caltech for a number of years. The research to be described was originated at Caltech in collaboration with Professor Y. C. Fung and was completed at the Aeronautical Research Laboratories.

The flutter of thin cylindrical shells is of particular importance. A disturbing fact about cylinder flutter has been a long-standing

discrepancy between theory and experimental evidence. Let us consider the flutter of a cylinder exposed to a supersonic flow directed parallel to the cylinder axis and along the outer surface (The flow over the outer skin of an Atlas missile rising through the atmosphere represents an analogous situation). Various theories have indicated that flutter could occur in a variety of wave forms (spiralling waves, traveling "checkerboard" wave patterns, etc.), and that these types of flutter would occur even on moderately thick shells. However, missiles launched into the atmosphere showed no evidence that flutter occurred. A preliminary series of wind tunnel tests confirmed (when no flutter could be found) that existing theories were unrealistic.

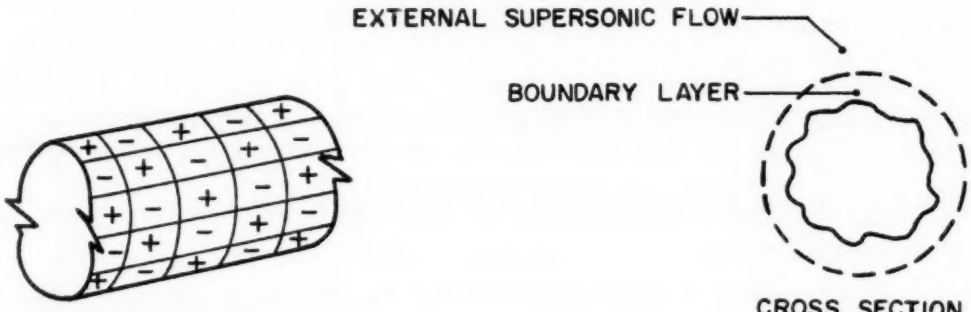
Elimination of other possibilities for the discrepancy led to a study of the effect of the viscous boundary layer on the cylinder (The boundary layer is the slow moving region of air surrounding any moving body. It consists of particles of air which "stick" to the body due to viscosity). The boundary layer has been under study for a long time and is of general interest to aerodynamicists, but flutter people have generally tried to ignore it.

It was decided to use a simple approach to the problem of flutter on a cylinder with a boundary layer because the problem is already complicated by the equations which must be used for cylindrical shells. The boundary layer was idealized as an annular region of uniform subsonic flow surrounding the cylinder. The velocity, pressure, and temperature in the boundary layer region shown below were assumed to be constants, so chosen to typify a true boundary layer.



The essence of the problem was to find the pressure on the surface of the shell corresponding to a small sinusoidal deflection

of the shell. The deflection pattern considered was of the type shown below, an oscillating "checkerboard" pattern.



CHECKERBOARD DEFLECTION

— = inward deflection

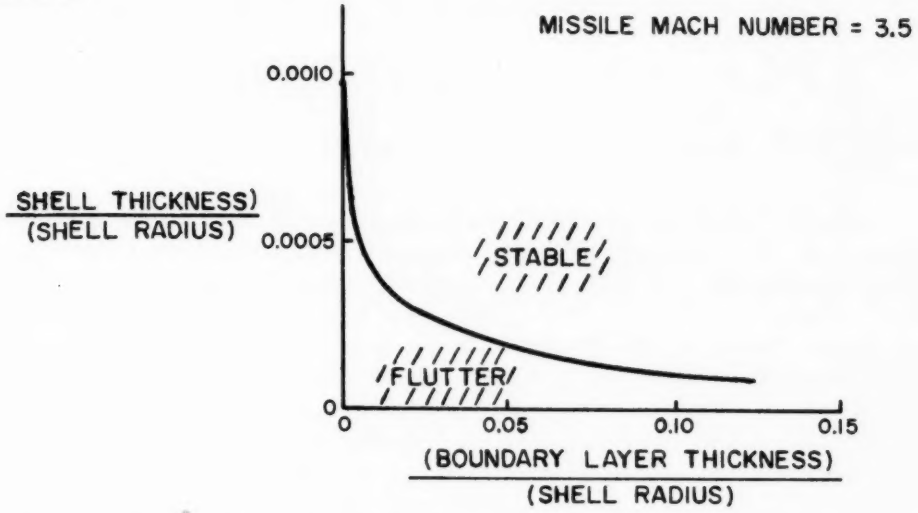
\+ = outward deflection

The problem was solved using linearized potential theory in the boundary layer region and by using linear piston theory for the supersonic region. Examination of the aerodynamic pressures exerted on the wall of such a cylinder revealed that the pressures were, for some cases, only 10% as large as for the same cylinder without the boundary layer!

The drastic effect of the boundary layer on such a cylinder leads one to speculate as to the physical process involved. It appears that the boundary layer acts as a cushion around the cylinder, partially shielding it from the higher velocity flow in the free stream. There is also some mathematical justification for this viewpoint. The boundary layer region, being subsonic, is governed by an elliptic differential equation. Elliptic equations are noted for their "averaging" nature. On the other hand, supersonic flow regions are governed by hyperbolic equations. In a pure supersonic flow (with no boundary layer), there would be regions of high and low pressures separated by very short distances on the surface of the shell. When the boundary layer is added, it provides a mechanism to cancel these pressures at the shell surface. This results in an overall lowering of surface forces due to shell displacement.

Up to this point the discussion has centered about the development of the aerodynamic theory to be used in the flutter equations. Of course, the goal of all flutter work is to provide criteria for the

prevention of flutter. Data are often presented in a curve as shown below, the so-called flutter boundary. This shows the shell thickness needed to prevent flutter as a function of the boundary layer thickness.



This figure is for a typical case of flutter in a "checkerboard" wave pattern with 22 standing nodal lines around the circumference of the shell. This is admittedly only one type of flutter, but it is an important type. It is known that other types of flutter are not affected as much by the boundary layer.

The stabilizing effect noted here for the flutter of a cylinder in a "checkerboard" pattern agrees approximately with experimental work recently completed by the Caltech group. In fact, the chief difficulty at Caltech was to make shells thin enough (and hence weak enough) to flutter at all.

It has been found theoretically that another type of cylinder flutter, the axisymmetric case, is stabilized greatly by structural damping. There is a possibility that the combination of the viscous boundary layer, as discussed here, and structural damping will make cylindrical shells stable enough that this type of flutter will never be a serious threat to missiles.

REFERENCES: Anderson, W. J. and Fung, Y. C., "Analysis of the Flutter of Cylindrical Shells with Boundary Layer," California Institute of Technology, GALCIT SM report 62-49, December 1962 (To be released as an OSR report).

BASJE

RAY R. HEER, JR., Nuclear Physics Division (AFOSR)

What does it stand for? It stands for AFOSR's Bolivian Air Shower Joint Experiment. It is the name of an experimental search for primary gamma rays from outer space - from our galaxy, or others.

Most probably, no one knows for sure who coined the name. It may have been Minoru Oda or Koichi Suga of the Tokyo Institute for Nuclear Studies. It was at this Institute that the genesis of, and first plans for, BASJE took place. Or it may have been George Clark or Bruno Rossi of the Massachusetts Institute of Technology, at which Institute discussions between Dr. Rossi and Dr. Oda led to final working plans for BASJE. Or it may have been Ismael Escobar V. of Mt. Chacaltaya Laboratory of the Universidad Mayor de San Andres at La Paz, Bolivia, at which location the experiment could be done. All of these men, all professors at their respective institutions, are integral, working members of the international group which is conducting this research which has come to be known as BASJE.

The reasons this group of scientists wanted to search for primary gammas, and the reasons for AFOSR interest in the search, are many. They include a need to know about the distribution of interstellar matter and the density of molecular hydrogen in space. The latter is a most important astrophysical problem. There is also the problem of learning about the environment near the center of our galaxy - cosmic dust precludes the use of optical methods so gamma ray astronomy proves useful here. And to extend this, one can look at nearby galaxies - at their gas or cosmic ray densities - and determine how they are like, or unlike, our own galaxy. Knowledge will be gained of high energy interactions and nucleonic cascades. Such knowledge might well be useful in radiation shielding studies associated with space travel. Another type analysis of the same data will add to our understanding of the plasma which occupies space between the sun and earth after certain types of solar activity. This will aid us in understanding the biological significance of near space. There are, obviously, many reasons.

This is not the only cosmic gamma ray experiment in the world. Explorer XI has detected primary gamma rays in the energy range from 10^8 ev to 10^{10} ev. But as with other types of cosmic radiation, gamma-flux (photons/cm^2 sec ster) decreases with energy, and the

flux at 10^{12} ev, and above, is simply too small to provide a statistical sampling of events which will be detected by instrumentation the size of that aboard Explorer XI. And to solve the astrophysical problems referred to above it is necessary to study the gammas in the energy range 10^{13} - 10^{15} ev. In this energy range extensive air showers (EAS) may result from gamma ray interactions with the atmosphere. But EAS may also result from the charged component of the cosmic radiation (H, He, etc) interacting with the atmosphere. It was necessary then to design an experiment which could detect and recognize the EAS which result from gamma ray interactions. It was no problem to design an experiment which would detect EAS; MIT had two such experiments in operation in 1960 when attention was focused on EAS from gammas. The problem was to recognize the gamma induced shower.

It was calculated that approximately 1 in every 3,000 EAS should be due to a primary gamma ray, the rest due to the high energy nucleonic component. But - this is the thing that made this particular experiment possible - it was predictable that a gamma induced EAS should have very few, if any, μ mesons (the main penetrating component of EAS) whereas ordinary EAS do have μ's. The approach, then, was to combine, in anticoincidence, an EAS detector with a penetrating particle detector. If both detectors record an event, it is highly probable that the event is due to a high energy nucleon, and it is discounted. If, however, only the EAS detector records an event, it is possible that the event is due to a primary gamma and the event is worthy of further analysis to positively establish whether or not it is due to a primary gamma ray. There was one other thing which could contribute to success; the higher above sea level - especially above 14,000 feet - the experiment was done, the greater would be the probability of detecting gamma induced EAS. A cosmic ray laboratory which fit this parameter perfectly is the one at Mt. Chacaltaya in Bolivia, situated at almost 18,000 feet above sea level. In addition there was already an AFOSR supported EAS experiment being performed at 13,000 feet at nearby El Alto de La Paz. It was natural and logical to move the El Alto experiment to Chacaltaya, combine it with a penetrating particle detector, and perform the gamma ray experiment at this site. In this way data could be collected on gamma ray induced EAS and ordinary EAS.

The experimental techniques and procedures were decided upon and in October 1960, AFOSR began formal support of the project. Dr. Suga came to MIT to be in charge of assembling the μ meson detector. It was calculated that 50 m^2 was approximately the minimum

size which could provide an efficient count rate. It was decided to build fifteen 4-square meter scintillator units in a 3 x 5 array, the extra 10 m^2 being a sort of insurance. Each scintillator unit consists of sixteen .25 m^2 scintillators, and each unit is viewed by a single 16" photomultiplier tube. In Figure 1, the μ meson detector is shown as the 3 x 5 open square matrix. Suga also designed and built the prototype of the transistorized logarithmic amplifier which is used in each unit. The equipment, which was built at MIT, was shipped to Bolivia in the Spring of 1961.

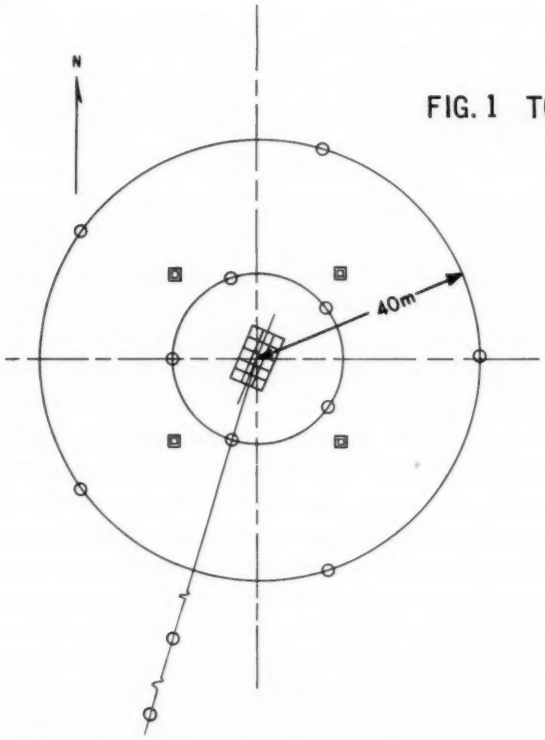


FIG. 1 TOP VIEW OF BASJE DETECTORS

(15) PENETRATING PARTICLE DETECTOR

(17) ELECTRON DENSITY DETECTOR

(5) FAST TIMING DETECTOR

The detector is shielded on the top and sides by a reinforced concrete structure which weighs over 100 tons. The concrete structure supports 160 tons of galena (lead sulfide) which has been loaned to the project by the Bolivian government. The concrete plus the galena plus 2cm of lead provide a path length of over 300 gm/cm^2 for any particle traversing the shield (Fig. 2). The lead serves as a multiplier of secondary showers from penetrating particles, giving an even wider differential in the signals from the two types of EAS. While the new meson detector was being built at MIT, the El Alto EAS detector was disassembled and reassembled at Chacaltaya. This detector at Mt. Chacaltaya consists of seventeen 1-meter sq

scintillators, fifteen of which sample the density of air showers over an area 80 meters in diameter and two of which are outside the 40 meter radius circle (open circles Fig. 1). At El Alto this detector had been used to determine direction of propagation of the shower as well as density. The direction determination is improved at Chacaltaya by addition of five fast timing detectors. Four of these are in a horizontal plane and the fifth is mounted 10 meters above this plane along the common vertical axis of all the detectors (open squares, Fig. 1). Next, seven lead glass Cherenkov detectors were added, also concentric about the common vertical axis and below the μ meson detector, (Fig. 2). They are many radiation lengths thick; therefore, they essentially exhaust the energy of particles which enter them. They act like a calorimeter and measure total energy incident on them, but they do not say anything about particle density. They give information of the distribution of energy in showers as a function of distance from the core. To complete the detector system there is a multiplate cloud-chamber above the galena (Fig. 2) which is useful in determining the characteristics of ultra high energy interactions and a neutron monitor which responds to neutrons produced from the interactions of the cosmic rays with the atmosphere. The neutron monitor is off to one

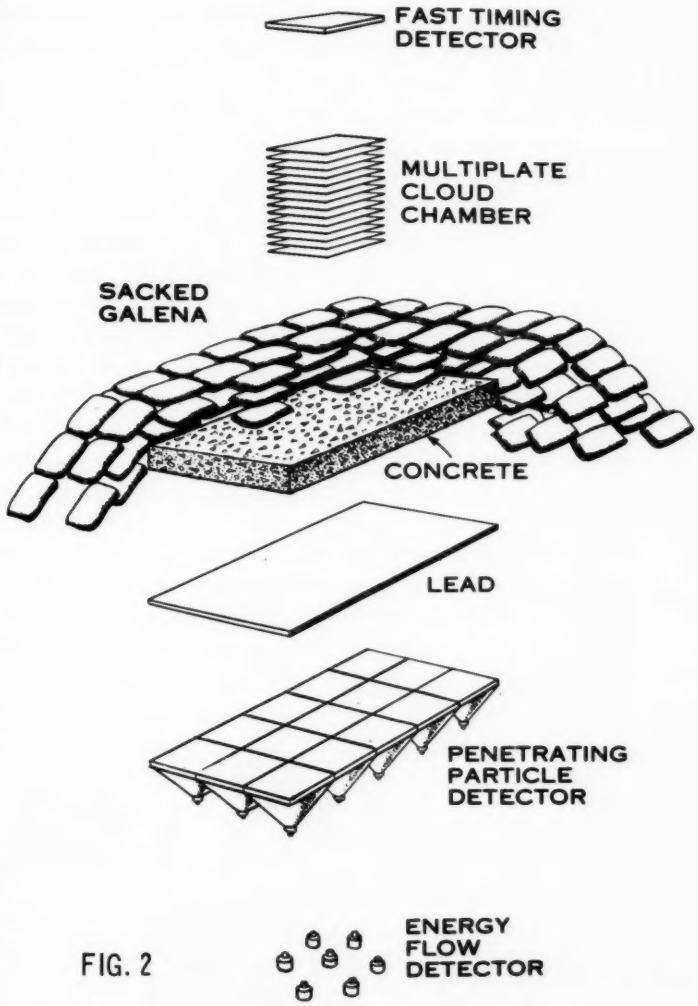
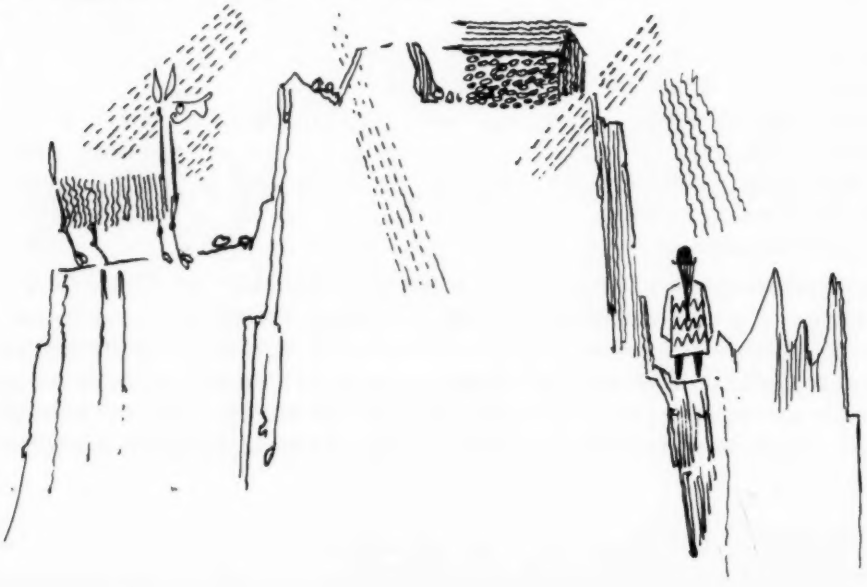


FIG. 2

side and will provide data on the distribution of low energy nucleons in ordinary air showers. All these data are put on punched cards in La Pax and sent to MIT for analysis on the IBM 7090 computer.

As of this time, almost a million EAS have been detected. Of this number, some 260 may be due to primary cosmic gammas. If all 260 events are from gamma rays, it must be said that there is no striking anisotropy (preferred arrival direction) in the gamma radiation in the range 10^{13} ev $< E < 10^{15}$ ev. Analysis indicates there is some enhancement of gamma radiation from near the galactic plane, but not by significant amounts. There is also much being learned from the ordinary showers which are rejected in the main gamma ray part of the experiment. For example, results from the ordinary EAS part of the experiment indicate a break in the size spectrum at 2 to 5 x 10^5 particles/shower. It is to be determined whether this break represents a change in the primary spectrum or a change in the nature of the nuclear interaction at about 10^{14} ev. In addition, the ordinary EAS data has been examined for anisotropy - is there a favored arrival direction. A preliminary result is that showers which are extremely μ-rich (showers which are precipitated by high Z primaries) do evidence some anisotropy.

After some six months of operation, data collection is in temporary abeyance. The data and theory are being subjected to extreme scrutiny to see if there are changes to be made which will enhance the probability that events counted as gamma ray candidates are actually the result of primary gamma ray interactions. One possibility is that the shielding will be increased by a factor of two as a means of increasing the signal to noise ratio.



A FAST RESPONSE *ANEMOMETER*

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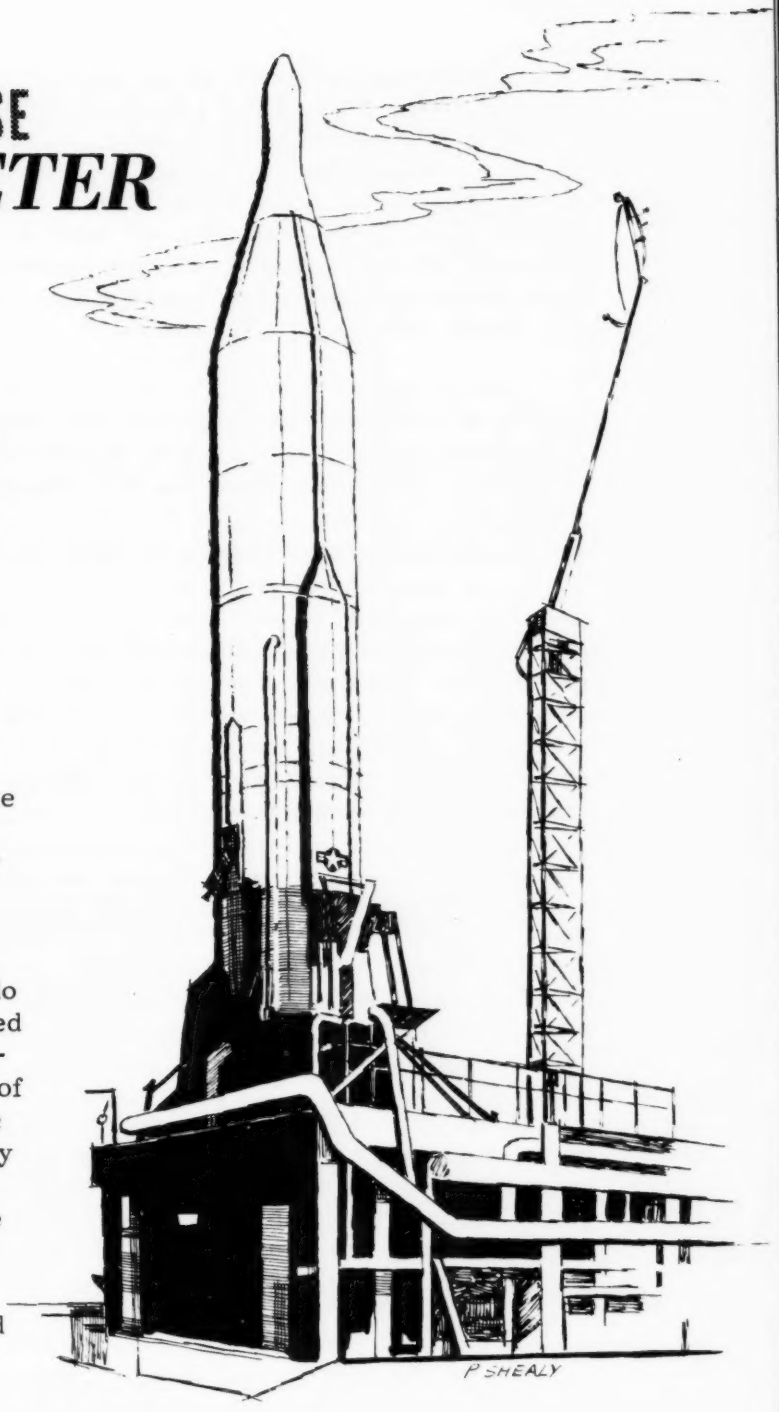
A missile, delicately poised on its launching pad prior to firing, is exposed to a variety of small scale wind influences -- shears, eddy currents, and rapid shifts in wind direction. The missile's response to these turbulent wind fluctuations while resting on its pad is largely unknown and is thus of concern.

But precise data on these small-scale wind velocity fluctuations are not readily available. Instruments with sufficient sensitivity and speed of response to measure this information do not exist. This need had led J. Chandran Kaimal of AFCRL to suggest the design of an extremely precise sonic wind loading on a stationary missile. Several types of sonic anemometers have been developed by others in the past, but none of these is particularly suited for measuring horizontal velocity components.



The operation of a sonic anemometer is based on the fact that the

velocity of sound depends on air density, temperature, and wind velocity. Thus, if you have a sound emitter operating at a given frequency and if you separate this source in space from a sound detector, the turbulent fluctuations in the air between the emitter and detector cause fluctuations in the phase of the signal reaching the detector. By measuring the phase difference between signals transmitted in opposite directions, it is possible to eliminate the effect of temperature and to derive information on just the velocity fluctuations.

The proposed AFCRL array consists of four detectors uniformally spaced in a square configuration on a horizontal plane. They are directed upward toward the sound emitter. The emitter facing down is located equidistant from the four receivers. The distance between the emitter and the plane of the receivers is equal to half the distance between two diagonally opposite receivers.

The emitter puts out a continuous acoustic signal at a constant frequency. In an undisturbed medium, the four receivers lie on a constant-phase surface -- that is, the signal has the same phase relationship at each of the receivers. In a disturbed medium, of course, the phase relationship differs, and phase comparison techniques indicate variations in wind patterns.

The AFCRL wind meter, as proposed, would operate at a frequency of 10 kcps. The direct phase comparison technique is insensitive to fluctuations in the amplitude of the received signals. This eliminates an important source of error found generally in other types of sonic anemometers.

In his report (AFCRL -62-1064), Kaimal treats several sources of possible error. Among these are wind-induced vibrations in the transducer supports, temperature variations affecting signal propagation, temperature changes resulting in changes of transducer characteristics, and the effect of the transducers themselves on the air flow along the acoustic paths.

All the limitations and possible sources of error, however, are small and construction of an operational instrument accurate to at lease within five percent should be easy to accomplish.

excitation of plasma OSCILLATIONS

D. G. SAMARAS, Directorate of Engineering Sciences (AFOSR)

Interest in space is associated with new fields of fluid dynamics and propulsion; namely, ion flow dynamics and nuclear propulsion, respectively. Some of these deal with plasma flows, ionic beams, and other advanced elements.

Plasmas exhibit the behavior of elastic continua; that is, any local departure from equilibrium generates restoring forces which try to oppose this departure thus causing oscillations.

Considerable theoretical work on plasma oscillations has been performed in the past; although only a limited number of experimental results are available today. Theory predicted many forms and types of oscillations which have not been confirmed yet by experiment.

In a recent paper M. Sellen and W. Bernstein of the Space Technology Laboratories under AFOSR contract (AF 49(638)-886) reported experiments in which oscillations have been detected in a synthetic plasma beam. These are associated with non-collisional electron thermalization. The experiments were in the lower energy region, i.e., the energy of the electrons injected was two to three times larger than that of the plasma.

The oscillatory condition occurs whenever a situation exists in which energetic electrons are injected into the plasma. They also found that the absolute value of the oscillation frequency is in reasonable agreement with the expected Langmuir plasma frequency.

In these experiments discrete frequencies rather than a continuous spectrum were observed. The width of the frequency band increases with increasing frequency. The amplitude of the oscillation decreases as the density or energy of the high energy electrons is decreased. The instability is damped when the temperature of the plasma is raised.

The results obtained (which may be considered near the threshold of the oscillation) seem to be in good agreement with the theory and other experimental results at higher energy ratios.

AFCRL Notes

LaVERNE E. WOODS, Research Information Office (AFCRL)

Two Aerobee sounding rockets will be fired from the White Sands Missile Range during the weeks of 18 and 25 February 1963. The objective of these flights is the measurement of neutral composition of the upper atmosphere by means of a rocket-borne mass spectrometer. It is expected that these vehicles, each with a payload of about 180 pounds, will attain a zenith of about 153 miles. During ascent the nose tips will be ejected to expose the mass spectrometers. Information will be telemetered to the ground. Recovery of the nose cones by parachute will be attempted. (Space Physics Laboratory)

In the second annular eclipse expedition to be conducted within a six-month period by AFCRL and Lockheed, perfect observational conditions were found at the South African observational site. The eclipse took place on 25 January and lasted a total of 37 seconds. An annular eclipse, unlike a total eclipse in which the solar disk is completely obscured by the moon, leaves the outer rim of the sun exposed. The exposed part of the sun is thus seen as a near perfect ring. The moon is silhouetted against the sun and this provides an ideal scientific condition for measuring the moon's precise shape. The observations were made near the town of Oudtshoorn, about 250 miles east of Capetown. Analysis of the eclipse photographs and motion pictures will be made by AFCRL, the Aeronautical Chart and Information Center, and Britain's University of Manchester. (Terrestrial Sciences Laboratory)

To be published next month is the "U.S. Standard Atmosphere, 1962," a compilation of idealized middle-latitude, year-round data on atmospheric temperatures and densities from sea level out to 700 km. The volume was prepared under the direction of the Committee on Extension of the Standard Atmosphere (COESA) representing some 29 U.S. scientific and engineering organizations. Mr. Norman Sissenwine of AFCRL was co-chairman of the group, and a considerable amount of the data on atmospheric properties was derived from AFCRL research. Purpose of the document is to provide all those whose R & D and operational activities involve atmospheric properties with a common reference source for making computations. The document is for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (Meteorological Development Laboratory)

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